Anomalous Loss and Propagation in Photonic-crystal Waveguides

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To begin with, we present a new semi-analytical method that can predict losses due to disorder in photonic-crystal waveguides (whereas brute-force methods are nearly prohibitive), use it to predict a measurable *decrease* in surface-roughness loss due to a bandgap in a realizable structure, and show what designs enable this effect [1]. Our method is based on the decades-old "volume-current method" (or 1st Born approximation to the Green's function), where a perturbation $\Delta\varepsilon$ is modeled as a current $\mathbf{J} \sim \Delta\varepsilon\mathbf{E}$ in terms of the unperturbed field **E**; we show, however, that a straightforward application of this idea for high-contrast nanophotonics can lead to an order-of-magnitude error in the predicted loss. Instead, the correct method for a surface "bump" with volume ΔV on an interface between ε_1 and ε_2 uses a current $\mathbf{J} \sim \left[\frac{\varepsilon_1+\varepsilon_2}{2}\alpha_{\parallel}\mathbf{E}_{\parallel} + \varepsilon\gamma_{\perp}\mathbf{D}_{\perp}\right]\Delta V$, where $\alpha_{\parallel}$ and $\gamma_{\perp}$ are polarizabilities that must be computed numerically (via a small calculation). Thus, we are able to quantitatively model an "apples-to-apples" comparison of a 3d strip waveguide with the same strip surrounded by a photonic-crystal slab, and further explore our theorem [2] that a photonic band gap, all other things equal, reduces radiation and does not change reflection loss from weak disorder.

A related prediction (which we presented in PECS V) is that reflection losses scale inversely with the square of group velocity, making slow-light devices a challenge. To minimize disorder, we consider a fiber-based design, and predict unusual slowing, reversing, and trapping of light by adiabatic tuning of a *negative* group-velocity fiber [3]. Finally, we turn to another fiber design which has recently been fabricated at MIT along with a nearby start-up, OmniGuide Communications Inc., which circumvents the problem of loss by exploiting a hollow core design to achieve record transmissions at 10.6μm wavelengths, and we show how this has recently enabled a life-saving new endoscopic surgical procedure.

[1] S. G. Johnson *et al.*, "Roughness losses and volume-current methods in photonic-crystal waveguides," *Applied Physics B*, in press (special issue, summer 2005).
[2] M. L. Povinelli *et al.*, *Appl. Phys. Lett.* **84**, 3639 (2004).
[3] M. Ibanescu *et al.*, *Phys. Rev. Lett.* **92** (6), 063903 (2004).
[4] C. Anastassiou *et al.*, *Photonics Spectra* (March 2004).